HARD DISK DRIVE HAVING DRIVE TEMPERATURE SELF-ADJUSTMENT FOR TEMPERATURE-SENSITIVE MEASUREMENTS

BACKGROUND OF THE INVENTION

1. Technical Field

[0001] The present invention relates in general to storage systems, and in particular hard disk drives. Still more particularly, the present invention relates to a hard disk drive capable of adjusting its temperature during testing using the hard disk drive's own hardware and sensors.

2. Description of the Related Art

[0002] A hard disk drive (HDD) is a digital data storage device that writes and reads data via magnetization changes of a magnetic storage disk along concentric tracks. The HDD is tested before being shipped to the customer. In addition, the customer often tests the HDD on a periodic basis after the HDD is operational. The HDD can be tested either for on/off failures or for gradual performance degradation.

[0003] On/off failures are failures in which an item fails, such as a cable breaks, a disk does not spin, a read/write head does not function at all, etc. Such failures are easy to identify and locate, but may require putting the HDD in an artificial condition, such as temperature extremes, high vibration, etc., that makes such an on/off failure more likely. Such conditions can cause undetected damage to the HDD, and thus on/off failure analysis has inherent limitation.

[0004] Gradual performance degradation occurs before an on/off failure. While such performance degradation may be caused by the same conditions that cause an on/off failure, evaluation of gradual performance degradation is typically performed under conditions much less severe than those that may cause an on/off failure.

[0005] Data produced by gradual performance degradation is used to conduct a predictive failure analysis. The gradual performance degradation data can be extrapolated or otherwise manipulated/evaluated to predict an ultimate on/off failure, or else an unacceptable performance degradation. This type of data extrapolation is referred to as Predictive Failure Analysis (PFA). PFA evaluates performance using either a "symptom driven" process or a "measurement driven" process.

[0006] The symptom driven process evaluates error logs. That is, when a failure in disk rotation speed, data read/writes, noise reduction, etc. occurs, an error log is generated, allowing the tester to identify the cause of the problem. Such a process is similar to an on/off failure analysis, except that the HDD has not entirely failed; rather only a partial function of the HDD has failed.

[0007] The measurement driven process detects Generalized Error Measurements (GEM), which detects changes in performance, although not necessarily functional errors. That is, a GEM may detect an increase in the distance between a read/write head and a disk surface, or an increase in noise in a digital signal read by the read/write head, but such increases do not cause a failure of the entire HDD or an HDD component, and thus are not considered "errors." Nonetheless, such GEMs are good indicators of potential problems, especially if the conditions causing the GEMs are allowed to persist or increase. For example, if the distance between the read/write head and disk surface (known as the "flying height" of the head) increases beyond an expected tolerance as the operating temperature of the disk surface increases, then a failure can be predicted if the temperature continues to rise beyond the normal operating temperature or remains at the normal operating temperature for an extended period of time.

[0008] Test condition parameters, including temperature, required during the detection of GEMs are established by a test engineer. For example, the test engineer may write a test program that measures flying height when the disk drive is operating at 30°C ± 4°. In order to keep the HDD at or near this range of temperatures, various methods are used in the prior art. Most such methods include test bench heating or cooling devices, which force regulated hot or cold air across or into the HDD until the desired test temperature condition is reached. Such

heaters/coolers require additional test bench footprint space, electrical outlets, feedback controls, and cost.

[0009] In addition, an operations computer may test its HDD periodically. Such testing also requires the temperature of the HDD to be within pre-determined levels during testing, typically, using the HDD's on-board cooling system (fan). However, such fans can only cool, no warm up, the HDD.

[0010] What is needed, therefore, is a method for regulating the temperature of an HDD, which is being tested, without the need for and use of additional hardware.

SUMMARY OF THE INVENTION

[0011] In view of the foregoing, the present invention is a hard disk drive (HDD) capable of controlling its own internal temperature during testing. A test program embedded in the HDD is run only within a pre-determined optimal test temperature range. The internal temperature of the HDD is kept within this pre-determined test temperature range by switching HDD operation modes back and forth between a higher heat generating Rapid Seek Mode and a lower heat generating IDLE mode. The HDD is thus kept within the optimal test temperature range without the use of external heating and/or cooling devices.

[0012] The above, as well as additional objectives, features, and advantages of the present invention will become apparent in the following detailed written description.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] The novel features believed characteristic of the invention are set forth in the appended claims. The invention itself, however, as well as a preferred mode of use, further purposes and advantages thereof, will best be understood by reference to the following detailed description of an illustrative embodiment when read in conjunction with the accompanying drawings, where:

[0014] **Figure 1a** depicts a preferred hard disk drive (HDD) and HDD tester used in the present invention;

[0015] **Figure 1b** illustrates additional detail of a disk platter stack used in the HDD of **Figure 1a**;

[0016] **Figure 2** is a chart of temperatures generated by different operations modes, Rapid Seek and IDLE, of the HDD;

[0017] **Figure 3** is a chart showing the non-linear relationship between Performance Measurement Units (PMUs), which quantify HDD operation anomalies, and time when the HDD is in an IDLE mode of operation;

[0018] **Figure 4** is a chart showing the linear relationship between PMUs and the temperature of the HDD;

[0019] **Figure 5** is a flow chart of steps taken to rapidly increase the initial internal temperature of the HDD for testing by activating the Rapid Seek Mode of the HDD;

[0020] **Figure 6** is a flow chart of steps taken using the Rapid Seek and IDLE modes to maintain the internal temperature of the HDD during testing; and

[0021] **Figure 7** is a flow chart of steps taken using the Rapid Seek and IDLE modes to ensure that the HDD is within a requisite temperature range needed to conduct a HDD test.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

[0022] With reference now to the figures and in particular **Figure 1a**, there is depicted a block diagram of a hard disk drive (HDD) **100** as contemplated by the present invention. HDD **100** has a set of hard disks **120**, which are rigid platters composed of a substrate and a magnetic medium. Since the substrate is non-magnetic, both sides of each hard disk **120** can be coated with the magnetic medium so that data can be stored on both sides of each hard disk **120**.

[0023] An actuator arm **124** moves a slider **132**, which is gimbal mounted to the actuator arm **124**. The slider **132** carries a magnetic read/write head **122** to a specified lateral position above the surface of the hard disk **120** when a voice coil motor (VCM) **126** swings the actuator arm **124**.

[0024] With reference now to **Figure 1b**, there is depicted additional detail of hard disks **120**. Hard disks **120** are a stack of hard disk platters, shown in exemplary form as hard disks **120a-b**. Preferably, more than two platters are used, but only two are shown for purposes of explanation. As a spindle motor **132** turns spindle **128**, each hard disk **120** connected to spindle **128** rotates at speeds in excess of 10,000 revolutions per minutes (RPMs). Each hard disk **120** has two surfaces, one or both of which can be magnetized to store data. Thus, hard disk **120a** is able to store data on both sides using read/write heads **122a** and **122b**. Hard disk **120b** stores data on only one side using read/write head **122c**. Thus, the system illustrated in **Figure 1b** is a two-platter three-head HDD. By swinging the actuator arm **124** (and thus causing the movement of slider **132** and read/write head **122**) and rotating the spindle **128** (and thus spinning hard disk **120**), read/write head **122** can be positioned above any spot above the surface of the hard disk **120**.

[0025] Referring again to **Figure 1a**, data reads/writes between a host system **102** and magnetic head **122** are under the control of a controller **104**. Controller **104** includes an interface (I/F) **112** coupled to host system **102**. Coupled to I/F **112** is a hard disk controller (HDC) **108**, which coordinates read/write operations, and controls modes of operation of HDD **100**, including Active Seek and IDLE Modes, about which more is discussed below.

[0026] Coupled to HDC **108** is a random access memory **106**, which caches data to be read/written at hard disk **120**. Read/write circuit **116** includes an analog-to-digital converter (ADC) and a digital-to-analog converter (DAC). The ADC is used to convert analog signals into digital signals for reads from the hard disk **120**. The DAC is used to convert digital values into appropriate analog signals for writes to the hard disk **120**. A microprocessor unit (MPU) **110**, under the control of a micro-program stored in read only memory (ROM) **114**, controls a VCM driver **118**. VCM driver **118** controls movement of the VCM **126** using a 9-bit DAC, which converts a digital control signal from MPU **110** into an analog control signal for VCM **126**. Typically, VCM driver **118** also works in coordination with a controller (not shown) for spindle **128**, to provide proper positioning of read/write head **122** above the surface of hard disk **120** during read/write operations.

[0027] Testing of HDD **100** is performed under the control of a HDD tester **136**. HDD tester **136** may be under the control of a standalone test computer (not shown) in a test laboratory, a program that is embedded in ROM **114**, or a test program in host system **102**, which is running HDD **100** under post-delivery operational conditions under the control of user or automatic hardware. HDD tester **136** samples data from read/write circuit **116**, evaluating the form (amplitude, noise, etc.) as well as content (ones and zeros) of the data. HDD tester **136** also receives temperature readings from thermal probe **130**, which measures the temperature inside the housing for HDD **100**. HDD tester **136** also receives test data from a test circuitry **134**, which includes circuitry for measuring flight height of read/write heads **122**, deformation of slider **132**, rotational speed of spindle **128**, seek travel time of read/write heads **122**, etc. HDD tester **136** is also able to control modes of operation of HDD **100**, including Rapid Seek Mode and IDLE Mode, via communication with HDC **108**.

[0028] As described above, HDD in an exemplary form has two seek modes: Rapid Seek and IDLE. During Rapid Seek Mode, more than 150 data seeks/second may occur. This generates a large amount of heat, mainly from current flowing through coils (not shown) in VCM **126**, but also due to metal friction caused by contacts against bearings (not shown) in VCM **126**. During IDLE mode, the disks continue to spin at normal operational RPM's, but VCM **126** is much less active, as there are perhaps as few as 5 data seeks/minute. This slower seek mode results in

much less current flowing through VCM **126**, resulting in much less heat dissipation from the coils in VCM **126**.

[0029] It is noted here that while the present invention uses Rapid Seek Mode and IDLE mode to illustrate different seek modes having different seek rates and heat generation/dissipation, the present invention contemplates any two seek modes having different seek rates with correlative different heat generation/dissipation levels. Thus a first seek mode is defined as any mode having a higher seek rate than a second seek mode, such that the first seek mode generates/dissipates more heat than the second seek mode. In a preferred embodiment, the first seek mode has a seek rate between 50 and 150 seeks/second, and the second seek mode has a seek rate between 1 and 50 seeks/minute.

[0030] The different amounts of heat generated by the Rapid Seek and IDLE modes are charted in **Figure 2**, which depicts temperature/time curves for the Rapid Seek Mode and the IDLE mode. As shown, the Rapid Seek Mode not only generates higher ultimate levels of heat after reaching steady state (reaching about 52°C after approximately 50 minutes), but Rapid Seek Mode also generates heat faster. Thus, the Rapid Seek Mode causes the drive temperature to reach 42°C in only 20 minutes, compared to the IDLE Mode that causes the drive temperature to reach 42°C in about 50 minutes.

[0031] Performance Measurement Units (PMUs) are quantified measurement units describing performance of a HDD. An exemplary PMU is IBM's Generalized Error Measurement (GEM) described above. PMUs describe performance deviations. A PMU does not represent a true error, but rather a deviation from optimal performance. Thus, PMUs are quantified for issues such as high or low read/write head flying height, signal noise from readings from the read/write head, channel noise, signal coherence, irregular signal amplification, etc.

[0032] As described in the graph of **Figure 3**, the number of PMUs increase during the time that the HDD is warming up. The longer the HDD is warming up, the more PMUs are generated, until the HDD reaches its steady temperature state. Thus, the graph of **Figure 3** has a linear relationship with the IDLE chart-line of **Figure 2**. This relationship is described in a more

general manner in **Figure 4**, which shows a linear correlation between the number of PMUs and the HDD temperature. This linear correlation is the same whether the HDD temperature is generated during Rapid Seek Mode or IDLE Mode.

[0033] The present invention takes advantage of the different heat generating rates/levels of the Rapid Seek Mode and the IDLE Mode shown in **Figure 2**. One method of utilizing this difference is shown in the flow-chart of **Figure 5**, which depicts an HDD being initially turned on for testing (block **500**). The HDD needs to be heated, as soon as possible, to a requisite test temperature range. To accomplish this heating, the HDD is initially run in Rapid Seek Mode (block **502**), until the HDD actual temperature (T_i) reaches the desired test temperature range (query block **504**), as determined by an HDD tester using a temperature probe within the HDD. This desired test temperature is defined/selected by a test program in the HDD tester. The desired test temperature range is defined as temperature "T" plus or minus acceptable deviation temperature "dT."

[0034] When running the HDD in Rapid Seek Mode has generated enough heat to reach the desired test temperature range, the HDD is then placed in IDLE mode (block **506**), since the HDD test program should be performed (or in some cases must be performed) while the HDD is in IDLE mode. The HDD test program is then run (block **508**). In a preferred embodiment, the test program is run at a steady-state temperature for IDLE mode. Referring back to **Figure 2**, while in the IDLE mode, once the HDD reaches about 42°C, the HDD will continue to remain at this temperature as long as the HDD remains in IDLE mode. However, by initially running the HDD in the Rapid Seek Mode, this steady state temperature is reached much faster (in about 20 minutes instead of the 50 minutes it would have taken the IDLE mode). Thus, the present invention allows the HDD to warm-up to the desired HDD test temperature in a significantly shorter amount of time, thus improving test throughput and resulting in significant savings in time and money.

[0035] After reaching an optimal test temperature, it would be advantageous to maintain such an optimal test temperature, assuming that remaining in IDLE mode alone will not keep the testing temperature steady. Referring then to **Figure 6**, an initial condition is assumed that the HDD test

is currently running in the proper test temperature range (block **602**). The HDD temperature is then constantly monitored by the HDD tester using the thermal probe inside the HDD, and this internal temperature is adjusted using the Rapid Seek Mode and IDLE Modes of the HDD. If the temperature (T_i) of the HDD is too high (query block **604**), then the HDD test program is suspended (block **606**) and the HDD allowed to continue in IDLE mode until it cools down enough to resume the HDD test. If the temperature of the HDD is too low (query block **608**), then the HDD test is suspended (block **610**), and the HDD drive is run in Rapid Seek Mode until the HDD is warm enough to continue the HDD test. As soon as the HDD is back within the proper temperature range, then the HDD test is resumed (block **612**) and continues until the HDD test is complete (query block **614**).

[0036] Periodically, an operational HDD needs to be tested. **Figure 7** describes such a situation and a preferred embodiment of the present invention. Assuming that an HDD is in normal operation in a computer system, a determination is made (query block **702**) as to whether it is time to conduct an HDD test. If so, then the HDD test program reads/determines what the requisite test temperature range is for the HDD test (block **704**). The HDD tester, using the temperature probe inside the HDD, compares the initial internal temperature (T_i) of the HDD with the requisite test temperature range ($T \pm dT$) for the HDD test program. If the initial temperature is too high (query block **706**), then the HDD is put into IDLE mode (block **708**) to cool down. If the initial temperature is too low (query block **710**), then the HDD is put into Rapid Seek Mode (block **712**) to heat up. When the HDD is in the proper temperature range, the HDD is put into IDLE mode (if not already) and the HDD test is run (block **714**). The temperature is continually monitored, and the HDD test is suspended whenever the HDD temperature is outside the test temperature range (blocks **708** and **712**). This monitoring/adjustment continues until the HDD test is completed (query block **716**).

[0037] The present invention therefore affords a method for reaching and maintaining a desired internal temperature of a HDD during testing operations using only existing hardware and existing HDD modes of operation. By using the Rapid Seek Mode, the HDD is quickly put in condition for testing. By maintaining the HDD within the proper range of temperatures as

described, false errors, caused by testing at an improper temperature, are avoided, and product yield is increased.

[0038] While the present invention has been described and illustrated using seek modes having different heat generation/dissipation levels, it is understood that the scope of the present invention includes the use of any two modes of HDD operation in which the HDD has two modes of operation, the first mode generating/dissipating more heat than the second mode of operation. Thus, more or less heat may be generated in different modes that have different speeds for the operation of spindle motor **132**, different clock/operation speeds of MPU **110**, etc.

[0039] It should be further understood that at least some aspects of the present invention may alternatively be implemented in a program product. Programs defining functions on the present invention can be delivered to a data storage system or a computer system via a variety of signal-bearing media, which include, without limitation, non-writable storage media (e.g., CD-ROM), writable storage media (e.g., a floppy diskette, hard disk drive, read/write CD ROM, optical media), and communication media, such as computer and telephone networks including Ethernet. It should be understood, therefore in such signal-bearing media when carrying or encoding computer readable instructions that direct method functions in the present invention, represent alternative embodiments of the present invention. Further, it is understood that the present invention may be implemented by a system having means in the form of hardware, software, or a combination of software and hardware as described herein or their equivalent.

[0040] While the invention has been particularly shown and described with reference to a preferred embodiment, it will be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention.